

Solar Energy Conversion Materials By Design And Recent Developments

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Abstract

Some Materials play a key role in various aspects of solar energy conversion. Presently available materials are generally deficient in performance, cost, stability or some combination thereof.

New materials systems guided by the interplay between rational design, high-throughput screening and theory, are needed to improve the performance of light absorbers, photovoltaic materials and photo-electrodes, catalysts, thermo-electrics, and infrastructural aspects of solar energy conversion systems. Further polymer solar cells and dye selenized solar cells are being studied now-a-days with great interest all over the world. They have the great potential for the future. The introduction of nanotechnology also has raised a lot of expectations.

Introduction (Building Block of Solar panel)

Photovoltaic's are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons. The photovoltaic effect refers to photons of light exciting electrons into a higher state of energy, allowing them to act as charge carriers for an electric current. The photovoltaic effect was first observed by Alexandre-Edmond Becquerel in 1839.

The term photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Virtually all photovoltaic devices are some type of photodiode.

Assemblies of photovoltaic cells are used to make solar modules which generate electrical power from sunlight. Multiple cells in an integrated group, all oriented in one plane, constitute a *solar photovoltaic panel* or "solar photovoltaic module," as distinguished from a "solar thermal module" or "solar hot water panel." The electrical energy generated from solar modules, colloquially referred to as *solar power*, is an example of *solar energy*. A group of connected solar modules is called an "array."

Photovoltaic cell is simply a wafer of semiconductor in which there is a junction between N and P type materials. On exposure to light, a photovoltaic cell produces a voltage of about 1 volt, compatible for a torch battery.

The silicon which is expensive to make in pure form, is in the form of thin wafer, to catch as much light as possible recently as cost effective we use some other materials ((InGa)Se₂ thin films, as used in photovoltaic (PV) devices, is primarily based on studies of its base material, pure CuInSe₂) for this purpose.

Materials used in solar cells (photovoltaic cells) plays a key role in solar energy conversion to electricity, fuels, and heat. Materials used in photovoltaics have traditionally been derived from research and development advances in other technology fields (e.g., Si from microelectronics industry, GaAs from optoelectronics industry), and as a result, the range of materials currently available for use in photovoltaics is highly limited compared to the enormous number of semiconductor materials that can in principle be synthesized for use in

photovoltaics. Here we will not forget to mention that the Ultimate Efficiency of a silicon Photovoltaic cell in converting sunlight to electrical is less than 30 %

Similarly, high-efficiency thermoelectric and thermo-photovoltaic converters coupled to solar concentrators have the potential to generate electricity at converter efficiencies from 25 to 35%. Significant progress has been made in these areas over the last decade, particularly by exploiting nanoscience and nanotechnology. Further fundamental research can lead to cost-effective materials that enable efficient solar-thermal energy utilization systems. Solar concentrators and hot water heaters call for new low-cost polymer-based materials/composites, while new solar thermal storage materials are required for several solar thermal conversion applications.

Determining the suitability of materials for photovoltaics is currently not a systematic process. For example, one of the most widely used semiconductors for thin-film photovoltaic cells is copper-indium-gallium-diselenide ($Cu_xGa_{1-x}InSe_2$). It was unexpectedly discovered that small area $Cu_xGa_{1-x}InSe_2$ cells work very well, despite being polycrystalline and containing many point defects, because sodium diffuses from glass substrates into the $Cu_xGa_{1-x}InSe_2$ film, interacts with grain boundaries, and reduces recombination. Had the initially undesired sodium diffusion not occurred, it is not clear that $Cu_xGa_{1-x}InSe_2$ technology would have reached its current state of development. This example points out the importance of experimentally testing films with many combinations of elements, even if there is no underlying heuristic or formal theoretical prediction suggesting that such combinations might have desirable properties. Since there are enormous numbers of alloy compositions to try, high-throughput screening methods are needed.

Furthermore, promising polycrystalline thin-film solar cells based on CdTe and $CuInSe_2$ are dramatically affected by the grain structure resulting from growth on foreign substrates, intentional and/or unintentional doping by impurities, the nature of the active junction, and ohmic contacts; all these processes and effects are poorly understood. A basic understanding of these issues would facilitate a revolutionary advance in the performance and economic viability of polycrystalline thin-film PV.

High Throughput Experimental Screening Methods For Discovery Of Designed Materials

A big research challenge here is to find appropriate and efficient tests of specific photovoltaic properties that enable testing for millions of material combinations. Materials synthesis is often not itself the bottleneck in an approach, owing to relatively straightforward vapor deposition methods for multiple source deposition of elements to form compounds; the more difficult challenge is often to develop experimental methods for properties-based materials selection. As an example, the energy band gap of the materials could quickly be determined by measuring the absorption spectrum. Some information on the rate at which recombination occurs could be determined by measuring the photoluminescence efficiency. Conceivably, arrays of solar cells could be made to directly determine quantum efficiency, fill factor, and open circuit voltage; in this case, contact-less methods for properties measurements would be highly desirable. Pumpprobe spectroscopic techniques could be used to determine the cross-section for impact ionization (multiple electron-hole pair generation). Ideally, such screening methods will identify good candidates for more thorough photovoltaic testing.

Nanoengineered bulk materials may indeed be a key to achieving high-performance bulk thermoelectric materials. Understanding the role and stability of the interface between the nanomaterials and the matrix is essential in order to effectively optimize the materials. An effective interface must be thermally stable and promote electron transport while impeding phonon transport. Interface issues such as diffusion and segregation processes, doping and composition of the nanostructures, differential thermal expansion, and chemical contrast are essential for investigation.

It has been demonstrated experimentally that the phonon thermal conductivity of super lattices can be significantly smaller than the theoretical minima of their constituent bulk materials (Costescu et al. 2004). Modeling suggests that it is the incoherent superposition of interface reflection of phonons that is the major cause of phonon thermal conductivity reduction (Chen 2001; Chen et al. 2003).

We need to gain a basic understanding of novel materials for spectral control (Fleming et al. 2002; Greffet et al. 2002). Photonic crystals, plasmonics, phonon-polaritons, coherent thermal emission, left handed materials, and doping with lanthanides are concepts from the

optics community that can be exploited for the spectral control components required in TPV systems.

Heat transfer surfaces for water heaters call for polymer/composites with high mechanical strength, UV degradation resistance, high thermal conductivity, and concentrator support structures requiring polymers with high mechanical strength and a low thermal expansion coefficient. The thermal conductivity of most polymers is 0.2 to 0.4W/m-K. An order-of magnitude increase in thermal conductivity is needed to make polymers competitive. New composite materials hold the promise of high mechanical strength and high thermal conductivity. Surface modifications are needed for photon and thermal management.

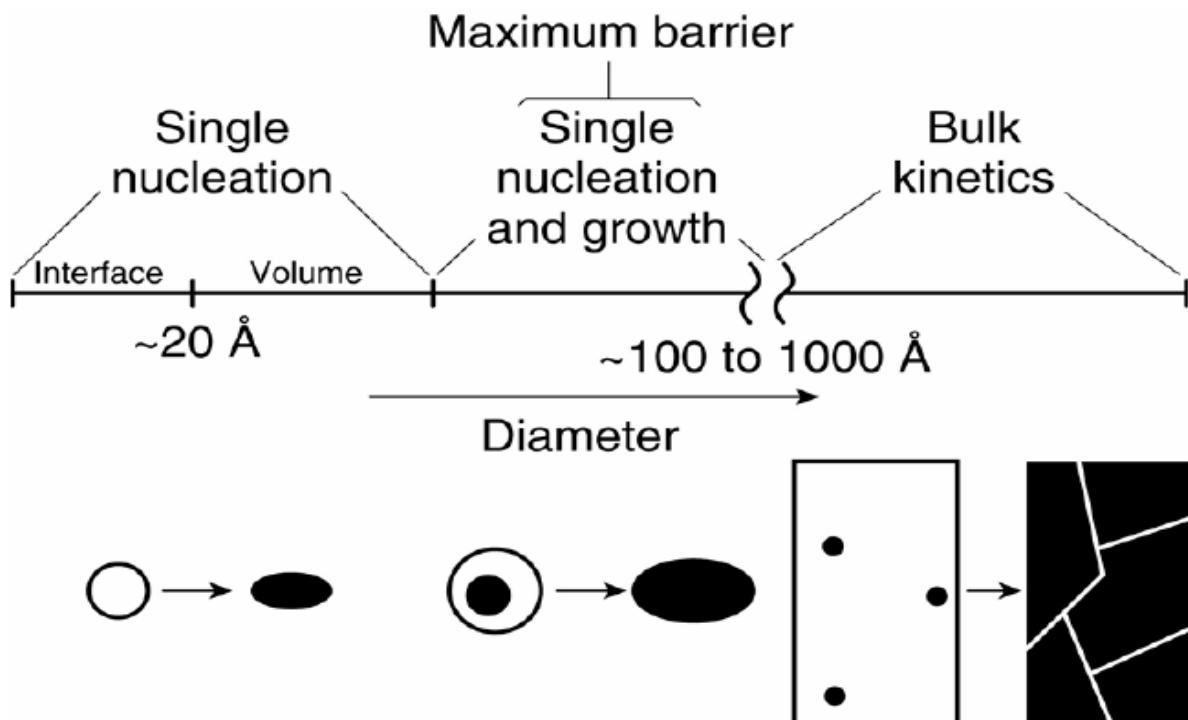


Illustration of various size regimes of the kinetics of solid-solid phase transitions. Defects, which act as nucleation sites, are indicated by round marks in the cartoon of the bulk solid.

Mirrors and glass that are dirt repelling can significantly increase efficiency and reduce cleaning cost. Surface engineering is also needed to prevent scale formation in solar thermal heat exchangers. Fundamental research on particle-surface interactions and solid precipitation and deposition processes can help solve these challenges.

Thermal Storage Materials must have high latent heat density ($>0.3 \text{ MJ/kg}$) and sufficiently high thermal conductivity for enhanced thermal energy charge/discharge processes. Recent developments of nanocrysttal polymer composites can be the key to a stable cycling solution for thermal storage. The unique characteristics of solid-solid structural transformations in nanocrystals can lead to a new generation of thermal storage materials. Present thermal storage materials are limited by the lack of reversibility of structural transformations in extended solids. In contrast, nanocrystals embedded in a “soft matrix” can reversibly undergo structural transitions involving a large volume change per unit cell. This is because a structural transition in a nanocrystal may proceed through a single nucleation event per particle (see Figure). Further, a nanocrystal can change shape and volume without undergoing fracture or plastic deformation. In addition, the barrier to a structural transition depends strongly on the size of the nanocrystals so that the hysteresis and kinetics of the structural transition can be controlled

Potential Impacts, Conclusion And Recent Development

An Research & Development investment in basic science and technology targeting solar-related materials is extremely relevant to the efficiency and cost goals in the solar area. Although there are several materials available to make thin-film PV cells today, an ideal material has not yet been found. Experimental and theoretical screening could discover several direct band-gap semiconductors that have band-gaps ranging from 0.7 eV to 2.5 eV, function well in PV cells, and are made from elements abundant in the Earth's crust. New materials could lead to the development of devices that enable the achievement of a ~35% - efficient power conversion in concentrated solar systems. Further subjecting it to nano sciences Quantum dots may be able to increase the efficiency and reduce the cost of today's typical silicon photovoltaic cells. According to an experimental proof from 2006 (controversial results), quantum dots of lead selenide can produce as many as seven excitons from one high energy photon of sunlight (7.8 times the bandgap energy) This compares favorably to today's photovoltaic cells which can only manage one exciton per high-energy photon, with high kinetic energy carriers losing their energy as heat. This would not result in

a 7-fold increase in final output however, but could boost the maximum theoretical efficiency from 31% to 42%. Quantum dot photovoltaics would theoretically be cheaper to manufacture, as they can be made "using simple chemical reactions." The generation of more than one exciton by a single photon is called multiple exciton generation (MEG) or carrier multiplication.

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